SAND2019-12778C

Sandia National Laboratories

High-resolution imaging of warm x-ray sources with a Wolter optic on the Z Machine

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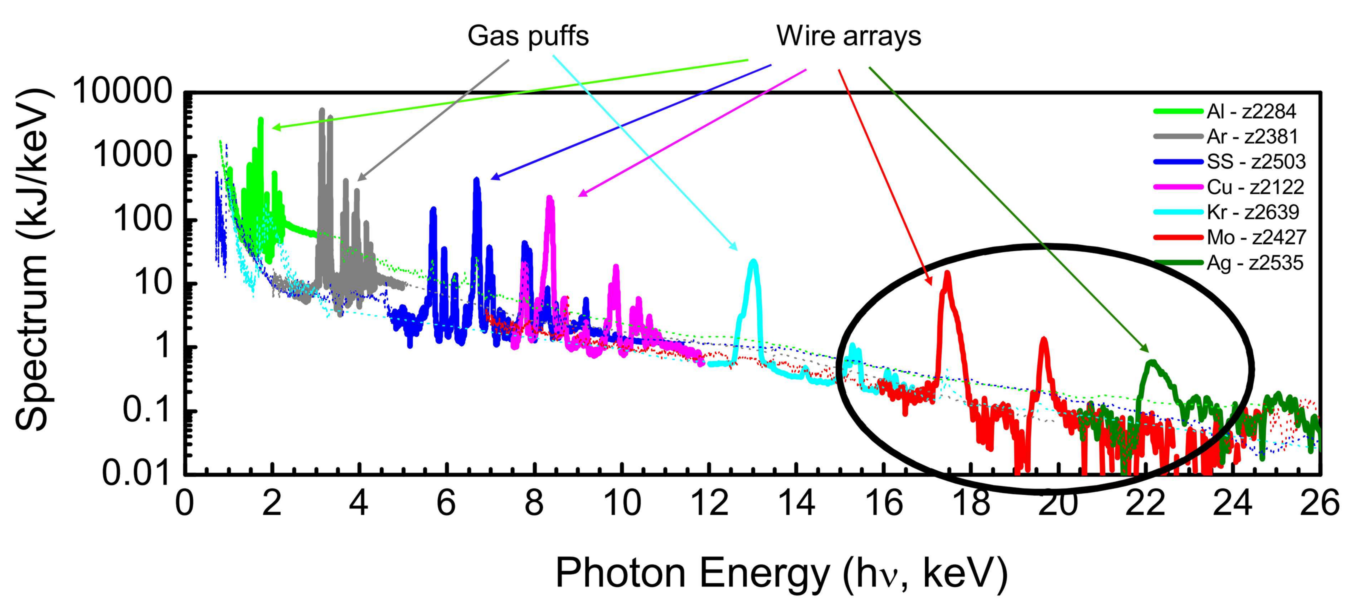
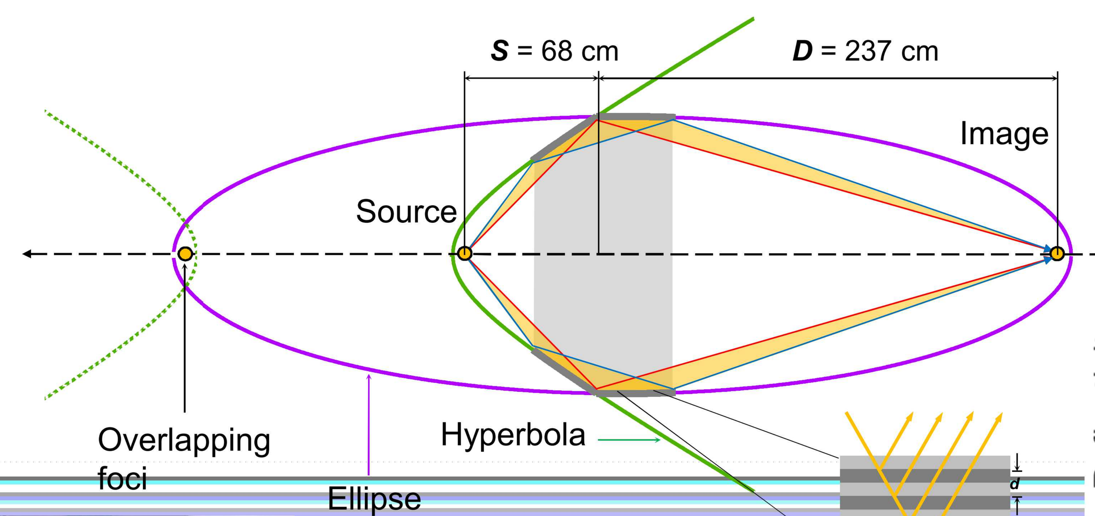
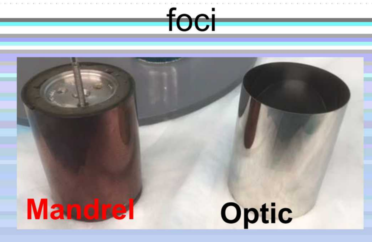
Wolter optics with multilayer mirrors push the limits of imaging warm (>15-keV) x-ray sources at hi-res. and large FOV

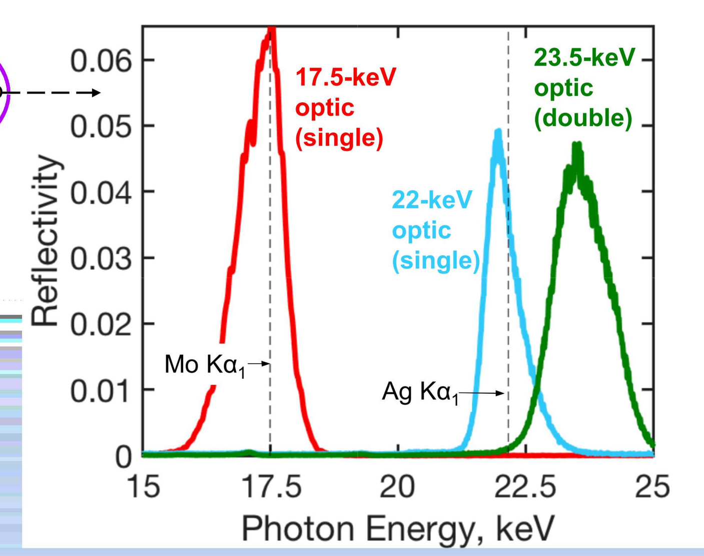


- SNL is developing *Non-thermal wire arrays* as >15 keV x-ray sources[1]
- The ability to image >15 keV sources was previously limited[2] by poor resolution (~1mm) and low signal/noise (~3)
- ***Wolter optics***,[3] adapted from observational astronomy and the medical field[4] are a promising option for high-resolution (~100 μm) imaging of warm x-ray sources with large (>5 mm) fields-of-view (FOV):





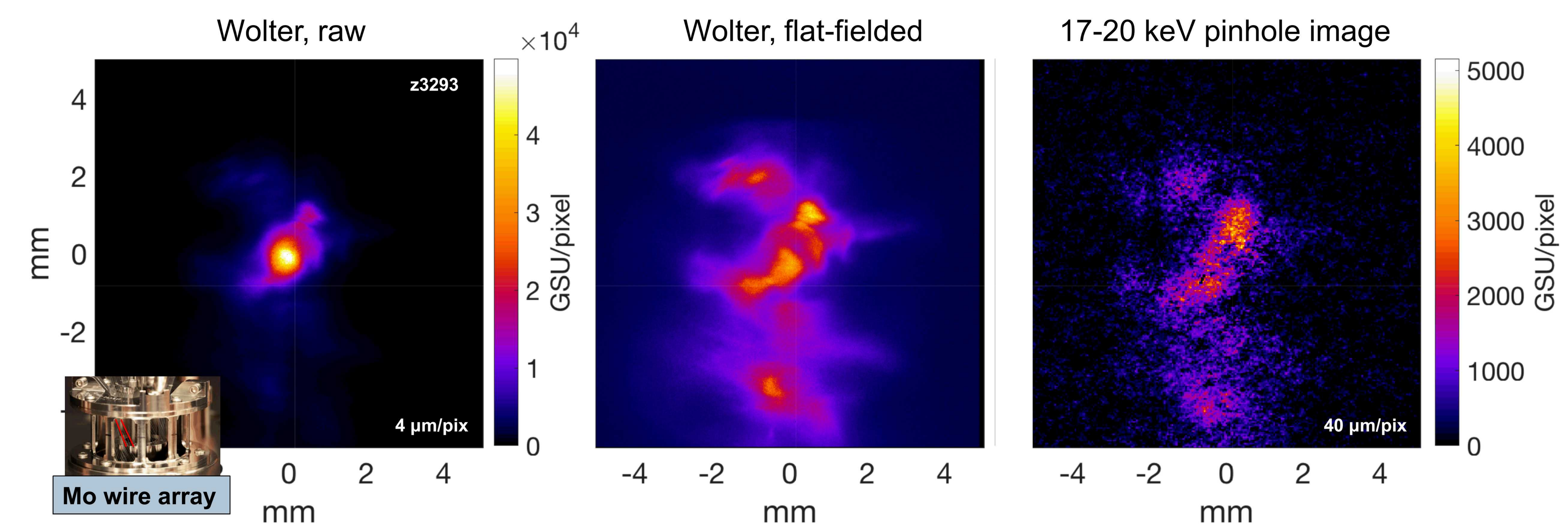
Multi-layer of Si/W increases collection efficiency & limits energy range



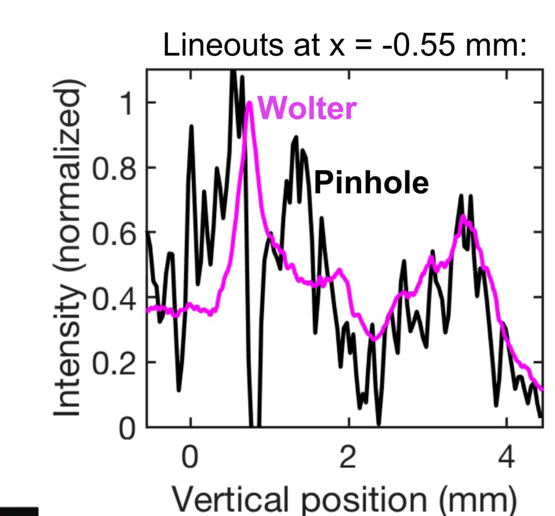
Wolter optic imager provides several advantages over traditional pinhole cameras and other imaging devices:

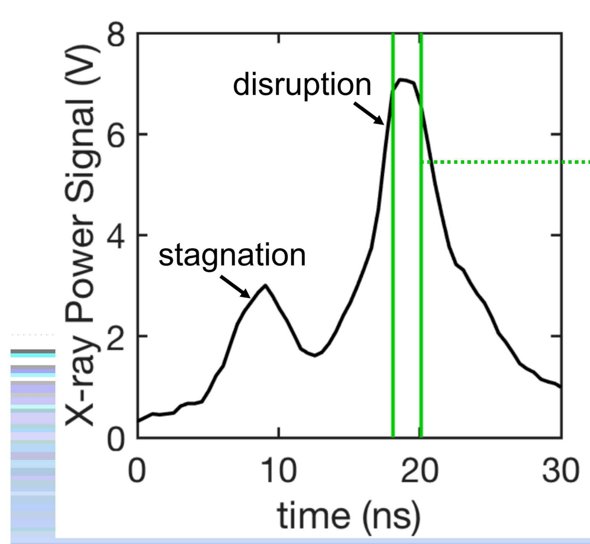
- Tunable band-pass enables ~monoenergetic imaging at a variety of energies
- Higher collection efficiency from focusing geometry and multilayer
- Limited aberrations off-axis allow large FOV

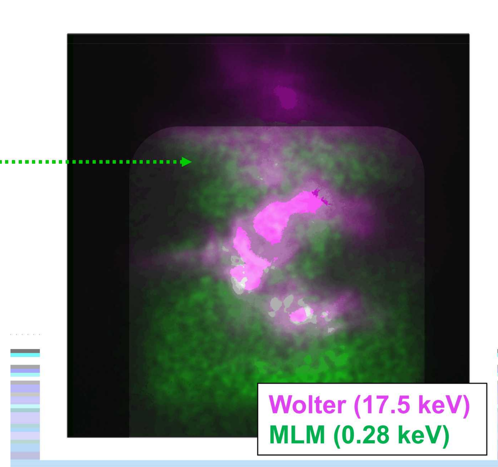
Wolter was successfully fielded on the Z Machine,[6] acquiring images of Mo wire arrays with a 17.5-keV optic



- Flat-fielded Wolter images have features similar to those seen in pinhole[2] images
- Features <200 microns in scale exist in the Wolter image, which are not observable below the ~1 mm resolution limit of the pinhole image
- Wolter demonstrates spatial resolution better than 150 microns, compared to ~1 mm in pinhole image and >20x increase in the signal/noise



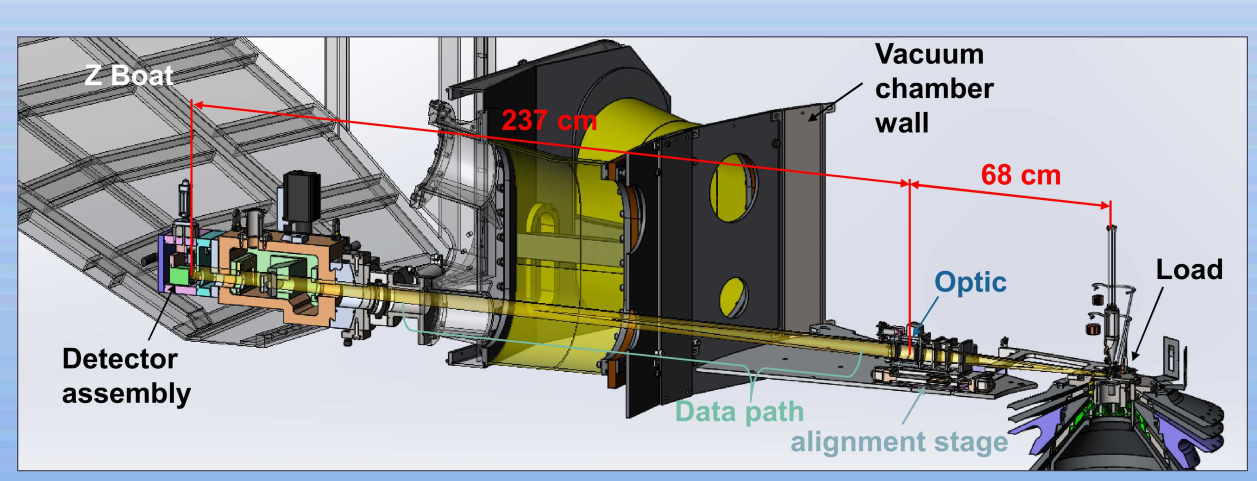




Overlap in structure between 17.5 keV emission and cold plasma during disruption phase of implosion

Composite image of Wolter @ 17.5 keV and 0.28 keV pinhole image[7] gated at time of max power for 17.5 keV x-rays

Mechanical design on Z



Mechanical design of the Wolter Imager on the Z Machine driven by the stringent alignment requirements of the optic and harsh Z environment

We are pursuing advanced imaging processing, aided by extensive calibration measurements

Throughput and point-spread function (PSF) vary significantly over FOV:

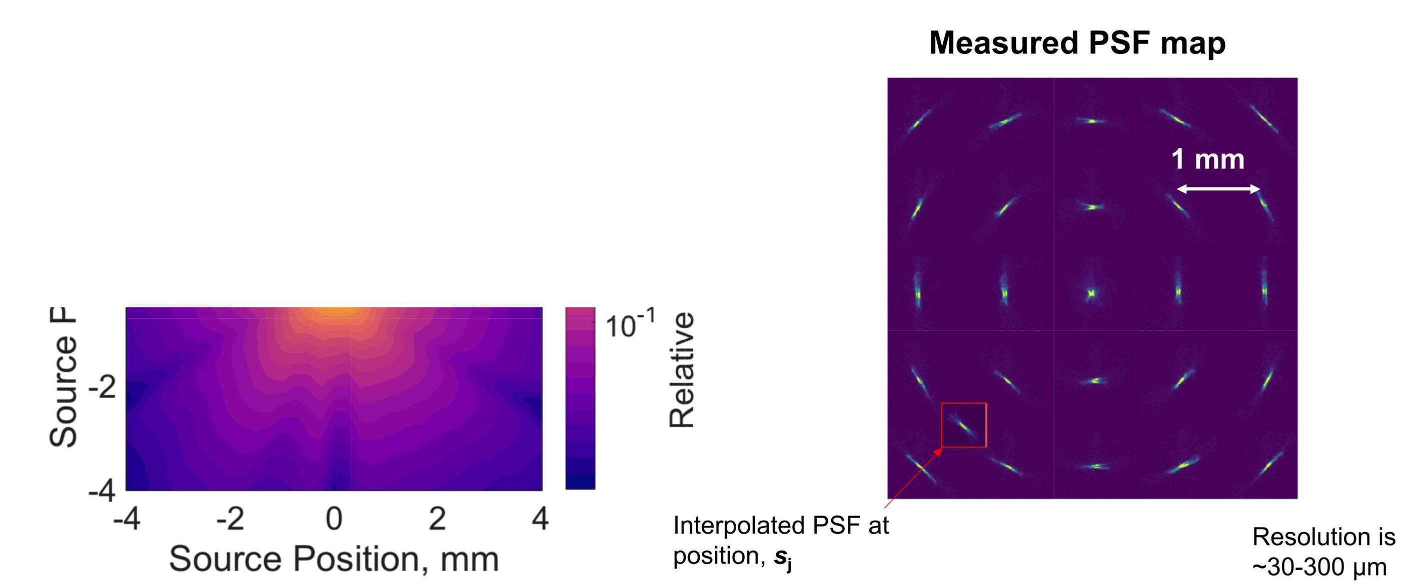


Image Deblurring

Model shift-variant PSF as sum of shift-invariant PSF modes:[8]

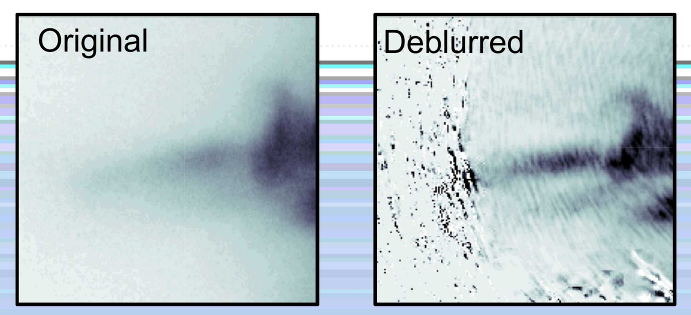
$$h(r,s)=\sum_{p}^{N} a_p(s)\, c_p(r-s)$$

Shift-variant PSF; coefficients; shift-invariant PSF modes

Image is sum of convolutions of PSF modes with source, *f* weighted by coefficients:

$$g=\sum_p c_p * (a_p \cdot f)$$

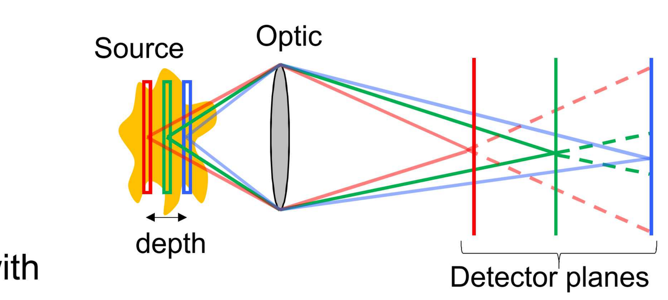
Deblur iteratively with expectation-maximization algorithm:

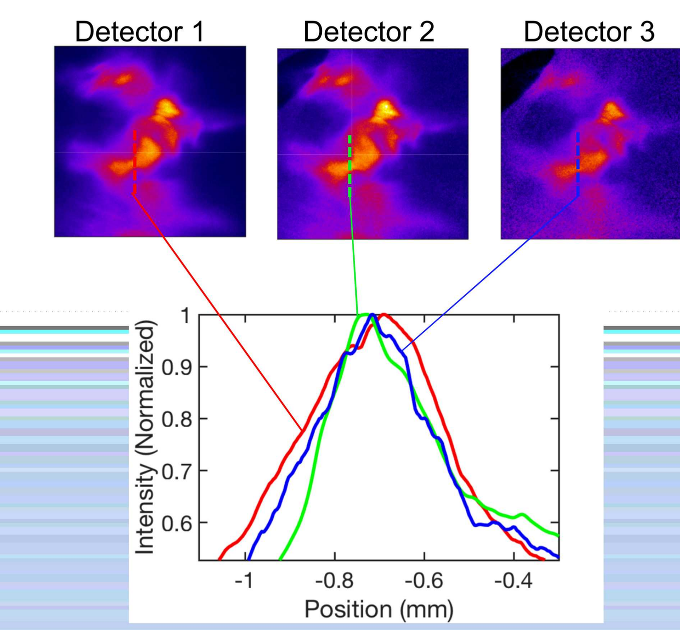


Deblurring better uncovers jet-like structures that may be from disruption physics and/or electron beaming

Multi-plane detector[9]

Take advantage of limited (~1mm) depth-of-focus:





Variation of feature width with detector plane may help localize its depth within source

Conclusions/Future Directions

- Wolter imager has successfully imaged Mo wire arrays on the Z Machine in the 17-18 keV energy band
- Wolter has demonstrated a spatial resolution better than 150 microns with high S/N over a greater than 5x5x5 mm³ FOV, significantly improving upon previous imaging capabilities
- Integration of hCMOS detector for time-gated imaging
- 22-keV optic will look at Ag wire array z-pinch sources

References

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